

## VLT-FLAMES observations of young stellar clusters in the Magellanic Clouds

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**Abstract.** We introduce our VLT-FLAMES survey of massive stars in the Galaxy and the Magellanic Clouds, giving details of the observations in our younger fields in the LMC and SMC. In particular we highlight a new O2.5-type star discovered in N11, and Be-type stars in NGC 346 with permitted Fe II emission lines in their spectra. We give an overview of the distribution of spectral types in these fields and summarize the observed binary fraction.

### 1. Introducing the VLT-FLAMES survey of massive stars

We have used the Fibre Large Array Multi-Element Spectrograph (FLAMES) at the Very Large Telescope (VLT) to observe massive stars in 7 fields in the Galaxy and Magellanic Clouds. Our target fields were centered on stellar clusters and were selected to sample a range of metallicity ( $Z$ ) and age. In practice this means observing fields in the three most readily accessible, yet differing environments, i.e. the Milky Way and the Large and Small Magellanic Clouds (LMC and SMC respectively), as summarized in Table 1.

Table 1. Summary of fields observed with VLT-FLAMES

	‘Young clusters’ ( $<5$ Myrs)	‘Old clusters’ (10-20 Myr)
Milky Way	NGC 6611	NGC 3293 & 4755
LMC	N11 (inc. LH9/10)	NGC 2004
SMC	NGC 346	NGC 330

FLAMES has 132 science fibres which are fed through to the Giraffe spectrograph. Notionally blue targets were selected from pre-imaging and the FLAMES-Giraffe combination was used to observe a total of 750 stars at high-resolution ( $R \sim 20,000$ ), at six wavelength settings. These observations form an unprecedented high-quality spectroscopic survey of OB-type stars, with coverage in the

blue optical region from 3850-4750 Å, and from 6400-6650 Å, to include the H $\alpha$  Balmer line.

The primary motivations and observational details of the survey have been presented by Evans et al. (2005), together with an overview of the Galactic data. A number of parallel studies are now underway using both the Galactic and Magellanic Cloud data to address issues such as:

- To determine the  $v \sin i$  distributions of the observed stars, is there evidence for a dependence with  $Z$ ? (cf. Maeder et al. 1999; Keller 2004).
- To obtain physical parameters (including CNO abundances) for a large, homogenous sample of OB stars. These will then be coupled with the  $v \sin i$  results to enable comparisons with evolutionary models that attempt to include the effects of rotation e.g. Maeder & Meynet (2000, 2001).
- To explore the  $Z$ -dependence of stellar wind mass-loss rates in O-type stars (cf. Vink et al. 2001; see de Koter et al., these proceedings).

## 2. Census of N11 and NGC 346 fields

Here we focus on the two younger fields in the Magellanic Clouds, N11 and NGC 346. These are the richest in the survey in terms of the numbers of O-type stars, and contain a number of interesting objects. The distribution of spectral types in these two fields is given in Table 2.

Table 2. Summary of numbers of stars observed in the N11 and NGC 346 fields

Field	O	B0-3	B5-9	Be	AFG	Total
N11	43	67	—	10	4	124
NGC 346	19	59	2	25	11	116

### 2.1. A new O2.5-type star in the N11 field

The N11 field includes the OB associations LH9 and LH10 (Lucke & Hodge, 1970), of particular interest in the context of sequential star-formation. Prior to our survey the best source of spectroscopic information in this region was the study by Parker et al. (1992), which found an apparently younger population in LH10, suggesting that star-formation in that association was triggered by the evolution of the most massive stars in LH9. Owing to observational constraints (such as crowding) we have not observed all of the stars in the Parker et al. study, but we have also explored the spectral content in other nearby regions.

Three O3-type stars were reported in LH10 by Parker et al., all of which were considered by Walborn et al. (2002) in their extension of the MK classification scheme to include a new O2 subtype (with one star from Parker et al. reclassified as an O2 giant). In principle the hottest ‘normal’ stars, there are still only  $\sim 10$

O2-type stars known. Here we report the discovery of a new star classified as O2.5 III(f\*). The spectrum (shown in Figure 1) lies between the standards published by Walborn et al. (2002, 2004) and so an intermediate O2.5 subtype is employed.

Interestingly the star is not in LH10, nor in any of the other denser gas regions in the field, and is  $\sim 4.5'$  to the north of LH10. The pre-FLAMES imaging reveals an apparent ionization front in the nearby gas; moving beyond the central region of LH9 and LH10, there is still clearly a lot to learn about the star-formation process in this region.

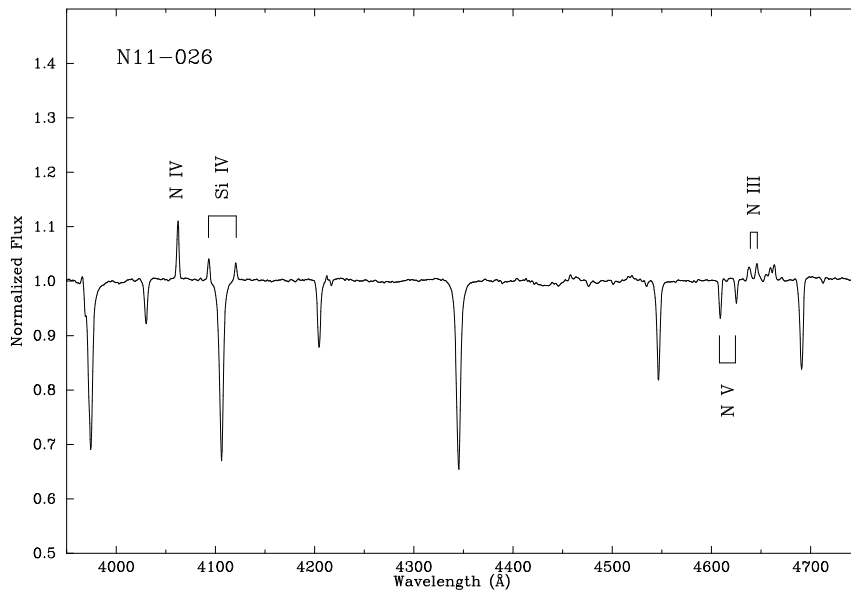


Figure 1. A newly discovered O2.5-type star in the LMC; for clarity the spectrum has been smoothed by a 1.5 Å FWHM filter. The lines identified from left to right are N IV  $\lambda$ 4058; Si IV  $\lambda\lambda$ 4089-4116; NV  $\lambda\lambda$ 4604-4620; NIII  $\lambda\lambda$ 4634-4640-4642.

## 2.2. Analysis of OB-type stars

Of the 62 O-type stars observed in these two fields, half were unknown prior to this survey; these data form the core of the analysis by Mokiem et al. (in preparation), which employs an automated approach to the problem of analysing such a large sample with contemporary model atmosphere codes (see Mokiem et al., 2005).

The FLAMES survey has also yielded a large number of early B-type spectra, spanning a range of luminosity classes. Our final aim is the consistent analysis of the whole sample; as a first step toward this, 15 of the narrow-lined (i.e. low  $v \sin i$ ) stars in NGC 346, and 21 in N11, have been analysed by Hunter et al. (in preparation) using the TLUSTY model atmosphere code (Hubeny & Lanz, 1995).

### 2.3. Be-type spectra

The observations in NGC 346 have revealed a number of Be-type stars with (permitted) emission lines from Fe II in their spectra. The morphology of the H $\alpha$  and Fe II profiles suggests that we are sampling a number of different projection angles; some display single-peaked emission, whereas others show twin-peaked emission, commonly interpreted as viewing a circumstellar disk edge-on. Figure 2 shows the blue-region spectrum of NGC346-023, with some of the stronger Fe II emission lines marked. This star is only 2.8' from the centre of the cluster and appears to be a genuine member; in a young field such as NGC 346 one could speculate that these stars might be somewhat different to classical Be stars, more often associated with later products of stellar evolution.

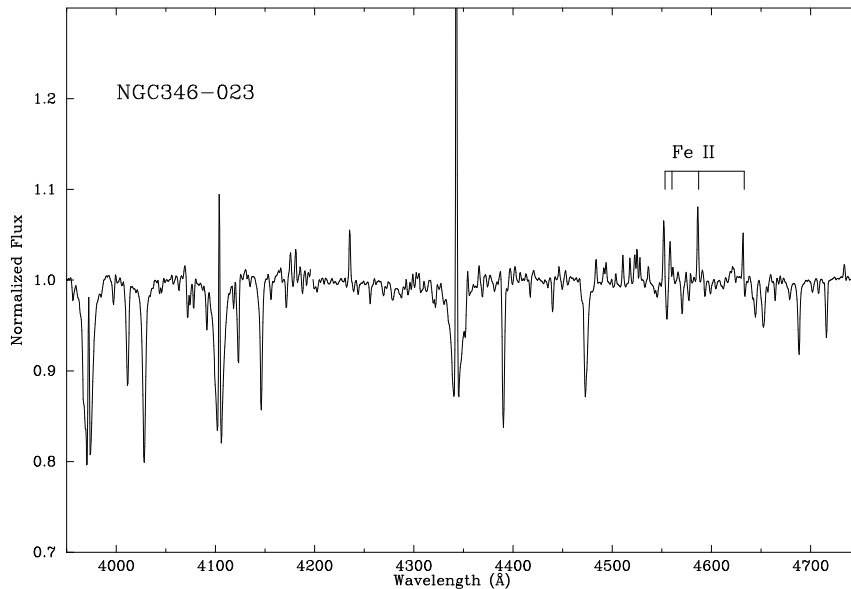


Figure 2. A Be-type star in the NGC 346 field that displays single-peaked Fe II emission lines; for clarity the spectrum has been smoothed by a 1.5 Å FWHM filter.

With regard to the relative numbers of Be-type stars in Table 2, one should not necessarily conclude that these provide further evidence for a  $Z$ -dependence of the Be-type phenomenon (cf. Maeder et al., 1999); the selection effects for the Be-stars are not well defined at the current time and we are looking further into this aspect of the survey.

### 3. Binary detection

Due to the significant scale of the FLAMES survey (in excess of 100 h VLT time), all of the observations were undertaken in service mode. In addition to the separate observations at different wavelengths, each wavelength setting in

the LMC/SMC fields was observed at least 6 times (to yield a greater signal-to-noise ratio). We are therefore very sensitive to detection of binaries. Indeed, the sampling is relatively good in the sense that we have observations at both small and large time-intervals (as shown in Figure 3), with the observations in N11 spanning a total of 57 days and those in NGC 346 covering 84 days.

To date, single and double-lined binaries have been found from relatively simple methods, i.e. from visual inspection when classifying the spectra, or from consideration of manual measurements of the stellar radial velocities from the principal hydrogen, helium and silicon absorption lines. More sophisticated methods are now being used to cross-correlate the individual spectra for each star, which will likely reveal further binaries (although not expected to be that significant an increase on the current number).

The FLAMES data are adequate to derive the periods of some of the newly discovered systems, the more interesting of which will be the subject of a future study. Using the numbers in Table 3, the binary fractions in the observed samples are 37% (N11) and 26% (NGC 346). These data place firm *lower* limits on the binary fraction. The fraction will likely increase slightly following use of the cross-correlation methods, and naturally some binaries may remain undetected as a consequence of the time sampling of our observations.

Table 3. Preliminary number of binaries detected in the FLAMES survey, compared to the total number of stars observed (for stars classified as earlier than B5, or as Be-type).

Field	O	B0-3	Be	Total
N11	43	67	10	120
<i>Binary</i>	<i>20</i>	<i>20</i>	<i>4</i>	<i>44</i>
NGC 346	19	59	25	103
<i>Binary</i>	<i>4</i>	<i>18</i>	<i>5</i>	<i>27</i>

#### 4. Summary

We have given an overview of the spectral content of our FLAMES fields in N11 and NGC 346. The data from these fields alone will form the basis for numerous studies in the future; indeed parallel analyses are now underway by various groups on different subsets of the data. To underpin these studies a comprehensive catalogue of the LMC and SMC fields, including spectral classifications, radial velocities and detection of binaries will be given by Evans et al. (in preparation).

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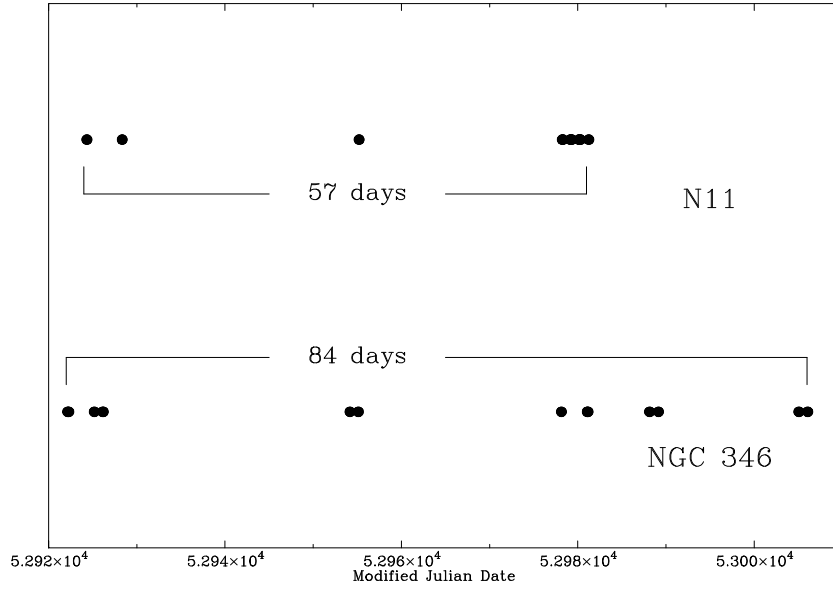


Figure 3. Schematic showing the time sampling of the FLAMES observations in the N11 and NGC 346 fields.

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